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POSTHARVEST QUALITY MAINTENANCE OF FRUITS AND VEGETABLES IN DEVELOPING COUNTRIES

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QUALITY COMPONENTS

Quality of fruits and vegetables is a combination of attributes or properties that give them value in terms of human food. Components of quality include appearance, texture, flavor, and nutritive value (Table 1). Growers and shippers are concerned that their commodities have good appearance and few visual defects. But to them a useful cultivar of a given commodity must score high on yield, disease resistance, ease of harvest, and shipping quality. Plant breeders have given these characteristics higher priority over flavor and nutritional quality. To receivers and market distributors, quality of appearance is most important; they are also keenly interested in firmness and long storage life. Traditionally, postharvest biology and technology research has concentrated on using appearance and texture as parameters for quality evaluation (28). Consumers see quality fruits as ones that look good, are firm, and offer good flavor and nutritive value. Although they buy on the basis of appearance and feel, their satisfaction is dependent upon good eating quality.

Fresh fruits, nuts, and vegetables play a very significant role in human nutrition, especially as sources of vitamins, minerals, and dietary fiber (4, 12, 25, 30). Postharvest losses in vitamin content, particularly vitamin C, can be substantial. These losses are enhanced by extended storage, higher temperature, low relative humidity, physical damage, and chilling injury (8). A large volume of data on composition and compositional changes of fruits and vegetables is available (14, 15, 29). But many gaps exist and further research is needed. As more becomes known about human

Table 1. Quality Components of Fresh Fruits and Vegetables.

Main Factors		Components
A.	Appearance (visual)	1. Size: dimensions, weight, volume 2. Shape & form: diameter/depth ratio, smoothness, compactness 3. Color: uniformity, intensity 4. Gloss: wax 5. Defects: external, internal a. Morphological b. Physical & mechanical c. Physiological d. Pathological e. Entomological
B.	Texture (feel)	1. Firmness, hardness, softness 2. Crispness 3. Succulence, juiciness 4. Mealiness, grittiness 5. Toughness, fibrousness
C.	Flavor (taste and smell)	1. Sweetness 2. Sourness (acidity) 3. Astringency 4. Bitterness 5. Aroma (volatile compounds) 6. Off-flavors and off-odors
D.	Nutritive value	1. Carbohydrates (including dietary fiber) 2. Proteins 3. Lipids 4. Vitamins 5. Minerals
E.	Safety	1. Naturally-occurring toxicants 2. Contaminants (chemical residues, heavy metals, etc.) 3. Mycotoxins 4. Microbial contamination

nutrition, additional compositional data will be needed. For example, it is not adequate to know how much total sugars are contained in a certain fruit. Information about individual sugars is important from the human nutrition as well as the sweetness standpoints.

Flavor is a complex sensation that involves perception of the tastes and aromas of many compounds. It is difficult to deal effectively with flavor in research programs because meaningful widespread taste testing is virtually impossible. An effective approach is to define the crucial components of flavor and then look at how these are affected by genotypes, cultural practices, and post-harvest handling procedures (18, 26). Objective analytical evaluation of critical components coupled with subjective evaluations by a taste panel can result in meaningful and useful information about flavor.

Numerous methods are available for evaluation of color, texture, and other quality attributes (1, 3, 6, 9, 10, 11, 20). However, there is a need for developing new objective and non-destructive methods for quality evaluation. It is also important to better define the interrelationships among various components of quality (appearance including color, texture, flavor, nutritive value) in various fruits and vegetables. In each case, an attempt should be made to correlate subjective and objective methods of quality evaluation. Such information is essential for selection of new cultivars by plant breeders, choice of optimum production practices by production physiologists, and redefinition of optimum postharvest handling procedures by post-harvest biologists. This total effort will no doubt result in the best quality fruits and vegetables possible for the consumers.

MATURITY AND QUALITY INDICES

Maturity indices are important for deciding when a given commodity should be harvested to provide some marketing flexibility and to insure the attainment of acceptable eating quality to the consumer. These two goals are not always compatible. The frequent need for shipping fruits and vegetables long distances has necessitated harvesting them at less than ideal maturity. This, in turn, has resulted in less than optimum quality to the consumer. Indices used for determining the legal maturity of fruits in most cases coincide with their minimum palatability.

Maturity Indices Currently Used and Their Limitations

For decades substantial effort has been directed by horticulturists towards the evaluation of maturity indices. Extensive data are available on morphological, physiological, and biochemical changes in fruits and vegetables during development, maturation, and ripening (14, 15). However, only a small portion of these data has been used in the establishment of maturity standards. In the

U.S. standards for grades, maturity is considered as one parameter of quality for many fruits and vegetables. It is defined as "that stage which will ensure proper completion of the ripening process."

Table 2 includes a listing of maturity indices used for selected fruits and vegetables. It is necessary for some commodities to define maturity indices for specific cultivars, production areas, and seasons. Although numerous objective indices for maturity are available, very few are actually used in practice because they are in most cases destructive and difficult to do in the field or orchard. Emphasis is on appearance factors, i.e., harvesting stage is determined by experience and judged largely by the visual appearance of the commodity.

Maturity vs. Quality

Most maturity indices are also factors of quality, but there are many important quality indices which are not used in determining optimum harvesting stage. The eating quality of fruits and vegetables cannot be accurately determined by appearance factors alone.

Timing of harvest (based on maturity indices) is complicated by the great differences which occur in the rate of development and maturation of individual plants, or organs on the same plant, bush or tree. This variability in maturation and ripening is especially important when once-over mechanical harvesting is used. Variability is related to preharvest cultural practices and environmental factors.

With a few exceptions (e.g., pears, avocados bananas), all fruits reach peak eating quality when fully ripened on the plant. Because of the constraints of the postharvest distribution system, fully-ripe fruits cannot be successfully delivered to the consumer except for roadside or pick-your-own type marketing situations. So compromises between optimum maturity and optimum quality have to be made.

For many vegetables, the optimum eating quality is reached before full maturity, e.g., leafy vegetables, immature fruits (cucumbers, sweet corn, green beans, peas, etc.). In this case, the problem frequently is delayed harvest which results in lower quality.

FACTORS INFLUENCING QUALITY AND ITS MAINTENANCE AFTER HARVEST

Many pre- and postharvest factors influence the composition and quality of fresh fruits and vegetables; these are:

1. Genetic factors: selection of cultivars, rootstocks.

Table 2. Maturity Indices for Selected Fruits and Vegetables.

Index	Examples
Elapsed days from full bloom to harvest	Apples, pears
Mean heat units during fruit development	Peas
Development of abscission layer	Cantaloupe
Surface morphology and structure	Cuticle formation on grapes, tomatoes Netting of cantaloupes Gloss of some fruits (development of wax)
Size	All fruits and many vegetables
Specific gravity	Cherries, watermelons, potatoes
Shape	Angularity of banana fingers Full cheeks of mangoes Compactness of broccoli and cauliflower
Solidity	Lettuce, cabbage, brussels sprouts
Textural properties	
Firmness	Apples, pears, stone fruits
Tenderness	Peas
Toughness	Asparagus
Color, external	All fruits and most vegetables
Internal color and structure	Formation of jelly-like material in tomato fruits Flesh color of some fruits
Compositional factors	
Starch content	Apples, pears
Sugar content, Acid content, sugar/acid ratio	Apples, pears, stone fruits, grapes, pomegranates, citrus, papaya, melons
Juice content	Citrus fruits
Oil content	Avocados
Astringency (tannin content)	Persimmons, dates
Internal ethylene concentration	Apples

2. Preharvest environmental factors
   a. Climatic: temperature, light, wind, rainfall, pollutants, etc.
   b. Cultural conditions: soil type, nutrient and water supply, mulching, pruning, thinning, control of pests and diseases, time and method of harvest, etc.

3. Harvesting stage: maturity, ripeness, physiological age.

4. Postharvest treatments: environmental factors, handling methods, duration between harvesting and consumption, etc.

5. Interactions among various factors.

Both quantitative and qualitative losses take place in horticultural crops between harvest and consumption. Our aim is to minimize these losses and to do so we must: 1) understand the biological and environmental factors involved in deterioration, and 2) use those postharvest technology procedures which will slow down senescence and maintain the best possible quality (13, 24, 27). Qualitative losses include loss in edibility, in nutritional quality, in caloric value, and in consumer acceptability of the products. Qualitative losses are much more difficult to assess than quantitative losses, especially since standards for quality and consumers' purchase power in developing countries are different than those in developed countries. For example, elimination of defects for a given commodity before marketing is much less rigorous in developing than in developed countries. This, however, is not necessarily bad, since appearance quality is somewhat over-emphasized in developed countries. A fruit or vegetable which is misshaped or has some blemishes may be as tasty and nutritious as one that is perfect in appearance. Any produce that is not spoiled (rotten) or totally unusable will have a market, if the price is right, in developing countries (16). Miles (21) proposed that an investigation should be conducted to determine the degree to which current trends in the consumption of fresh fruits and vegetables in the U.S.A. are indirectly the result of retailer demand for cosmetic qualities that are unrelated to flavor and nutritional quality; the degree to which there would be consumer acceptance of less blemish-free fruits and vegetables; the effect that lowered quality standards would have on the prices of fresh fruits and vegetables; and the effect that lower prices would have on consumption.

Biological and Environmental Factors Involved in Deterioration

Fresh horticultural crops are diverse in morphological structure (roots, stems, leaves, flowers, fruits, etc.), in composition, and in general physiology. Thus, commodity requirements and recommend-

ations for maximum postharvest life vary among various groups of commodities. However, they are all subject to the following biological (internal) causes of quality deterioration:

1. Metabolic changes associated with development, maturation, and senescence (respiration, compositional changes);

2. Mechanical injuries (cuts, bruises, abrasions, etc.);

3. Transpiration or water loss (shrivelling, wilting, desiccation);

4. Growth and development (sprouting and rooting in some commodities, elongation, etc.);

5. Incidence of physiological disorders (sunburn, freezing injury, chilling injury, etc.); and

6. Pathological breakdown (decay caused by bacteria and fungi).

The rate of biological deterioration depends on various environmental (external) factors such as temperature, relative humidity, atmospheric composition, pressure, etc. (7, 13, 24, 27). The relative importance of the deterioration factors depends upon the commodity (Table 3). Losses in quality and quantity in fresh fruits and vegetables can occur throughout the harvesting and postharvest handling systems and are cumulative (Table 4). Losses closer to the consumer level are more costly because they include not only direct losses of the commodity but also losses of energy and natural resources used in postharvest handling (16).

There is a need for an accurate and specific identification of the causes and extent of losses in quantity and quality for each commodity at each stage between harvest and consumption. Such detailed information is essential to pinpoint problem areas in the handling system and to set priorities for loss prevention efforts in every developing country. The principal objectives of postharvest technology are: 1) to maintain quality of the commodity between harvest and consumption, and 2) to reduce losses during harvesting, preparation for market, transport, storage, and marketing operations. In general, the level of technology currently used in postharvest handling of fruits and vegetables in developing countries is not adequate for realizing the above-stated objectives (2, 5, 7, 16, 22, 23). Adoption of new technological procedures is badly needed provided they fit local conditions. Transfer of "advanced" technology such as that used in developed countries without some adaptation and modification to suit specific local conditions can be counterproductive.

Table 3. Principal Causes of Postharvest Losses and Poor Quality for Various Groups of Fruits and Vegetables.

Group	Examples	Principal Causes of Postharvest Losses and Poor Quality (in order of importance)
Root vegetables	Carrots Beets Onions Garlic Potato Sweet Potato	1-Mechanical injuries 2-Improper curing 3-Sprouting and rooting 4-Water loss (shrivelling) 5-Decay 6-Chilling injury (subtropical and tropical root crops)
Leafy vegetables	Lettuce Chard Spinach Cabbage Green Onions	1-Water loss (wilting) 2-Loss of green color 3-Mechanical injuries 4-Relatively high respiration rates 5-Decay
Flower vegetables	Artichokes Broccoli Cauliflower	1-Mechanical injuries 2-Yellowing and other discolorations 3-Abscission of florets 4-Decay
Immature-fruit vegetables	Cucumbers Squash Eggplant Peppers Okra Snap beans	1-Overmaturity at harvest 2-Water loss (shrivelling) 3-Bruising and other mechanical injuries 4-Chilling injury 5-Decay
Mature-fruit vegetables	Tomato Melons Citrus Bananas Mangoes Apples Grapes Stone fruits	1-Bruising 2-Over-ripeness and excessive softening at harvest 3-Water loss 4-Chilling injury (chilling sensitive fruits) 5-Compositional changes 6-Decay

Table 4. Most Common Causes of Postharvest Losses in Fresh Fruits and Vegetables in Some Developing Countries.

Postharvest Handling Operation	Causes of Losses
Harvesting	1-Immaturity or overmaturity of the commodity 2-Inadequate field containers 3-Mechanical damage due to improper harvesting methods 4-Failure to protect the commodity from the sun 5-Delays before delivery to packinghouse or transporting to market
Preparation for market (in the field or at the packinghouse)	1-Failure to sort-out produce with serious defects and decay; inadequate cleaning 2-Inappropriate packaging resulting in mechanical damage, inadeuate ventilation and cooling, and increased decay 3-Failure to remove field heat (lack of cooling prior to shipment) 4-Lack of sanitation
Transport	1-Rough handling causing increased mechanical injuries 2-Lack of proper management of temperature, relative humidity, and ventilation during transit 3-Mixing of non-compatible commodities in the transport vehicle (different types of containers which are not easily stackable together, different temperature requirements, ethylene-producing and non-producing commodities) 4-Delays during transport
Handling at destination	1-Rough handling during loading and unloading 2-Exposure to undesirable enviornmental conditions 3-Delays in getting the commodity to the consumer 4-Improper ripening and storage practices 5-Lack of sanitation
Handling at home	1-Delays before consumption 2-Improper storage (lack of home refrigerators or other means of storage)

Non-biological (Socio-economic) Factors Involved in Deterioration

Several indirect and non-biological, but very important, factors contribute to postharvest qualitative and quantitative losses of fresh fruits and vegetables (16). These include:

1. Inadequate marketing systems. Growers can produce large quantities of good-quality fruits and vegetables, but if they do not have a dependable, fast, and equitable means of getting such commodities to the consumer, losses will be extensive. This problem exists in many locations within developing countries. It is accentuated by lack of communication between producers and receivers, and lack of market information.

Marketing cooperatives should be encouraged among producers of major commodities in important production areas. Such organizations are especially needed in developing countries because of the relatively small farm size. Advantages of marketing cooperatives include: 1) providing central accumulation points for the harvested commodity, 2) purchasing harvesting and packing supplies and materials in quantity, 3) providing facilities for proper preparation for market and storage when needed, 4) facilitating transportation to the markets, and 5) acting as a common selling unit for the members, coordinating the marketing program and distributing profits equitably.

Alternative distribution systems such as direct selling to the consumer (roadside stands, produce markets in cities, local farmers' markets in the countryside, etc.) should be encouraged. Production should be maintained as close to the major population centers as possible to minimize transportation costs.

Wholesale markets in most of the developing countries are in desperate need of improvement in terms of facilities and sanitation. These are overcrowded, unsanitary, and lack adequate facilities for loading, unloading, ripening, consumer packaging, and temporary storage. In several countries, there are plans to build better wholesale marketing facilities, but their implementation has been delayed more because of social and political than because of financial considerations.

2. Inadequate transportation facilities. In most developing countries, roads are not adequate for proper transport of horticultural crops. Also, transport vehicles and other modes, especially those suited for fruits and vegetables, are in short supply. This is true whether for local marketing or export to other countries. The majority of producers have small holdings and cannot afford owning their own transport vehicles. In a few cases, marketing organizations and cooperatives have been able to

acquire transport vehicles, but they cannot do much about poor road conditions.

3. Governmental regulations and legislations. The degree of governmental controls especially on wholesale and retail prices of fresh fruits and vegetables varies from one country to another. In many cases, price controls are counter-productive. Although intended for consumer protection, such regulations encourage fraud and provide no incentive for producing high quality produce or for postharvest quality maintenance. On the other hand, regulations covering proper handling procedures and public health aspects during marketing are, if enforced properly, very important to the consumer.

4. Unavailability of needed tools and equipment. Even if the growers and handlers of fresh fruits and vegetables were convinced of the merits of using some special tools and/or equipment in harvesting and postharvest handling, they most likely will not be able to find them on the domestic market. This is true of harvesting aids, containers, equipment for cleaning, waxing and packing, and cooling facilities. Most of these tools are neither manufactured locally nor imported in sufficient quantity to meet demand. Various governmental regulations in some countries do not permit direct importation by producers of their needs. It is imperative that the tools that will enable handlers to use recommended technology for a given situation be available for them to use. In many cases such tools can be manufactured locally at much lower cost than the imported ones.

5. Lack of information. The human element in postharvest handling of fruits and vegetables is extremely important. Most handlers directly involved in harvesting, packaging, transporting, and marketing in developing countries have limited or no appreciation for the need for or how to maintain quality. An effective and far-reaching educational (extension) program on these aspects is critically needed now and will continue to be essential in the future.

6. Poor maintenance. In many developing countries some good facilities which were built a few years ago are currently "out-of-order" or not functioning properly because of lack of maintenance and unavailability of spare parts. This problem is especially true of public sector facilities. Any new project should include in its plan adequate funds for maintenance to ensure its success and extended usefulness.

Kriesberg and Steele (19) stated that at each stage of the marketing system in developing countries there are forces exogenous to it which influence its development. Among political and economic factors are public policies, the general stage of technology, and

income levels and their distribution. Among social and cultural factors are urbanization, education and population growth and its characteristics. Other factors working more directly on the marketing systems include the kinds and quantities of commodities available for market, and consumer demand and commodity preferences.

All non-biological factors influencing quality deterioration are much more difficult to change than the environmental factors which control biological deterioration. However, to be successful, any improvement program must take all factors into consideration.

QUALITY STANDARDIZATION AND INSPECTION

Grade standards are developed to identify the degrees of quality in the various commodities which aid in establishing their useability and value. They are important tools in the marketing of fresh fruits and vegetables because of the following factors: a) they provide a common language for trading between growers, handlers, processors, and receivers at terminal markets; b) they assist producers and handlers in doing a better job of preparing fresh horticultural commodities for market and appropriate labeling; c) they provide a basis for making incentive payments for better quality; d) they serve as the basis for marketing reporting; and e) they help settle damage claims and disputes between buyers and sellers.

The first U.S. Grade Standards were developed for potatoes in 1917. Currently there are more than 150 standards covering 80 different commodities. In addition, several states also have mandatory minimum quality standards. The International Standards for Fruits and Vegetables, which have been defined by the Economic Commission for Europe (since 1954) and the Organization for Economic Cooperation and Development, have provided the basis for EEC standards currently in effect for 38 commodities. Developing countries must use these quality standards for their commodities which are exported to EEC countries. With very few exceptions, no quality standards are used for fresh fruits and vegetables destined for local marketing. The establishment of simple grade standards and their use for local distribution in developing countries can be major steps which would help reduce fraud and deception in packaging and encourage high and uniform quality. Enforcement of these standards will require a well-trained group of inspectors in each country and an effective extension program to inform all producers and handlers about the standards. They need to be convinced that proper standardization and inspection would promote trust and encourage commerce.

POSTHARVEST TECHNOLOGY PROCEDURES IN RELATION TO QUALITY

Commodity requirements and recommended conditions for optimum quality maintenance and postharvest life are the same regardless

of the distribution system (direct marketing, local marketing, export, etc.). However, the type of appropriate technology needed to provide such conditions will depend upon the distance and time between production and consumption areas as well as intended use (fresh vs. processing). In selecting the proper postharvest technology procedures, one should remember the following:

A. The technology used elsewhere is not necessarily the best for use under conditions of a given developing country. Many of the recent modifications in postharvest technology in developed countries have been in response to the need to economize in labor, materials, and energy use, and to protect the environment. It is useful to study the currently used practices in other countries and to select those which are appropriate for local conditions.

B. Expensive equipment and facilities without proper management are useless. People who operate such facilities are more important than their level of sophistication.

C. Commodity requirements can be provided using simple and inexpensive methods in many cases. For example, proper temperature management procedures include:

1. Protection from exposure to the sun,
2. Harvesting during cooler parts of the day or even at night,
3. Adequate ventilation in containers and non-refrigerated transport vehicles,
4. Possibly simple and inexpensive cooling procedures such as evaporative cooling and use of cool-night ambient air, and
5. Expedited handling.

D. Mechanical injuries are major causes of losses in quality and quantity of fresh horticultural commodities in all handling systems. Their incidence and severity can be greatly reduced by simple modifications in harvesting and handling procedures and by informing all personnel involved about the need for careful handling.

Solving the postharvest technology problems in a given country will require cooperation and effective communication among all the research and extension personnel involved. Postharvest horticulturists need to coordinate their efforts and to cooperate with production horticulturists, agricultural marketing economists, engineers, food technologists, and others who may be involved in various aspects of the marketing systems. In most cases, solutions to existing problems in the postharvest handling system require use

of available information (17) rather than any new research. Following is a proposed program for improving the postharvest handling system in a developing country:

1. Survey the magnitude and causes of losses in quality and quantity during harvesting and postharvest handling of major commodities.

2. Survey available tools and facilities for harvesting, packing, transport, storage, etc., for each commodity in its important production seasons and areas.

3. Evaluate the impact of simple modifications in the handling system (picking stage and method, type of containers, quality sorting, etc.) on quality maintenance and losses.

4. Extend information about recommended harvesting and handling procedures to all those who can use it. All appropriate extension methods for the intended audiences should be used.

5. Identify problems which need further research, carry out research and extend any new information when completed.

FUTURE RESEARCH NEEDS

Additional research in both developed and developing countries is needed to improve our understanding of quality and its postharvest maintenance in fresh fruits and vegetables. The objectives of this research should be to:

A. Better define components of quality (appearance, texture, flavor, nutritive value) and their interrelationships for various fruits and vegetables destined for the fresh market or for processing.

B. Develop objective and non-destructive methods for determination of appearance and textural quality and optimum maturity which are related to their flavor and nutritional quality.

C. Evaluate the effects of preharvest factors (genetic, environmental, and cultural) on flavor and nutritional quality of fruits and vegetables.

D. Develop multiple maturity indices related to distance to market and intended use of the commodity (fresh market, processing, etc.).

E. Relate maturity indices at harvest to the final organoleptic

acceptability by the consumer and to nutritional quality.

F. Study the effects of any proposed changes in harvesting and postharvest handling practices on quality and safety attributes.

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